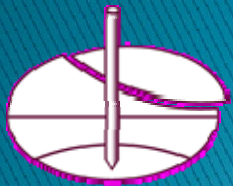


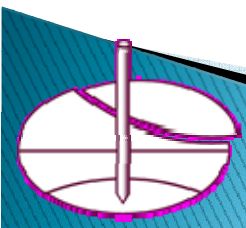
Evaluation of Eurocode 7
Example 2.3 – PILE IN CLAY
ETC 10

Adriaan van Seters
Fugro Ingenieursbureau BV
The Netherlands

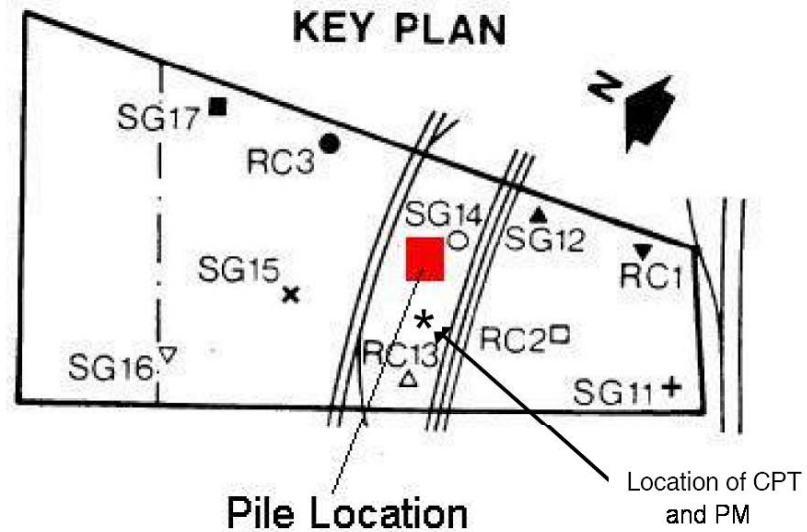
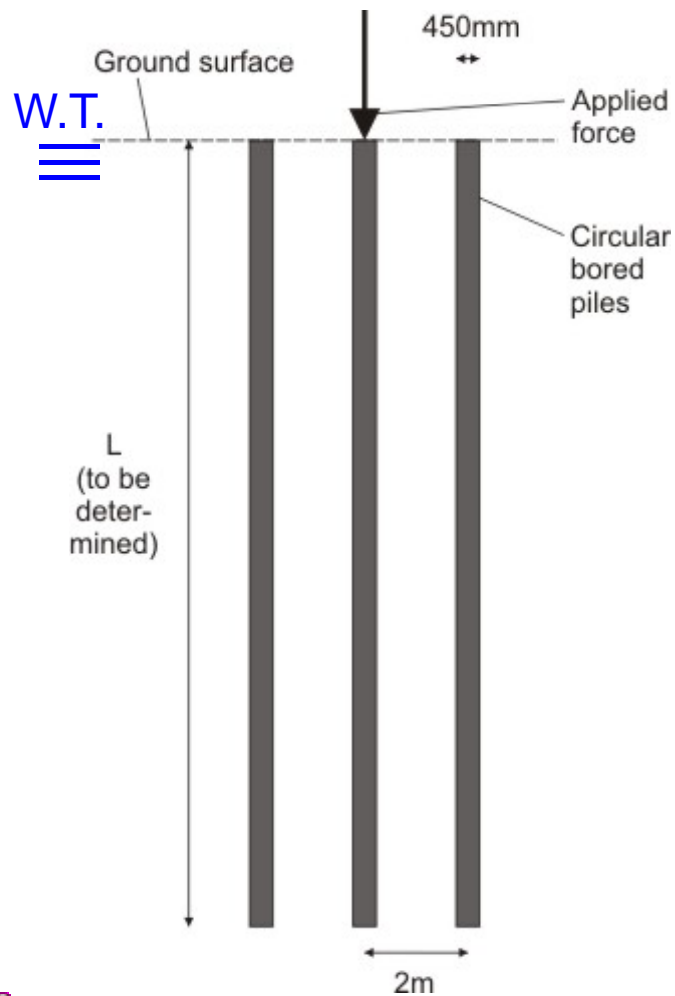


Contents – Example 2.3 – Pile in Clay

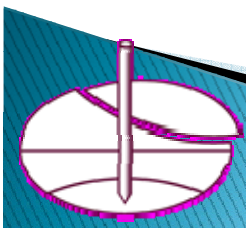
- Introduction in example
- SLS–design – source of parameters
- Characteristic values of C_u – profile
- SLS – required pile length
- ULS – shaft friction / endbearing computation
- Design Approaches used
- Load/strength/resistance factors
- ULS – computed pile length
- Conclusions



Pile in Clay – Outline of problem



Soil data: boreholes 13,14
SPT's – borings 11, 12, 14 -17
CPT
Pressuremeter tests PM2, PM3
Triaxial UU – borings 11, 12, 14 -17



Soil Conditions

0 – 3 to 4 m

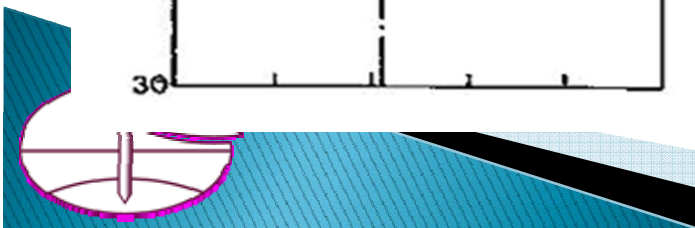
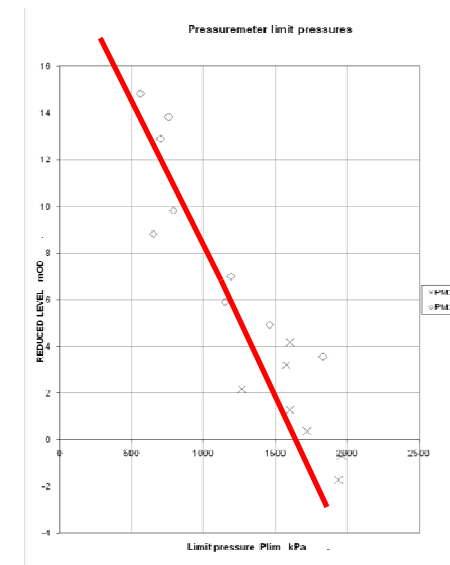
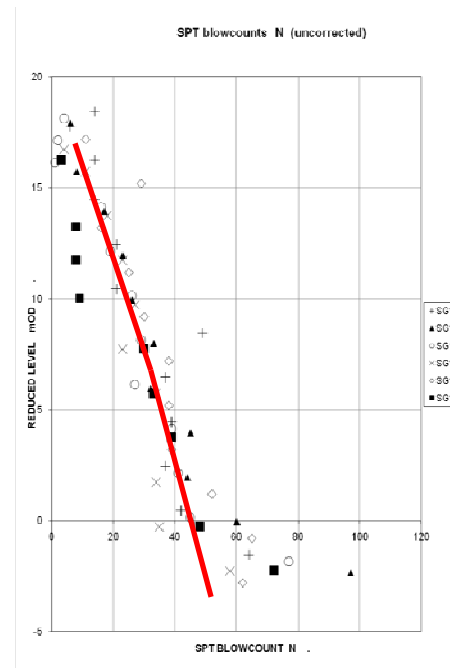
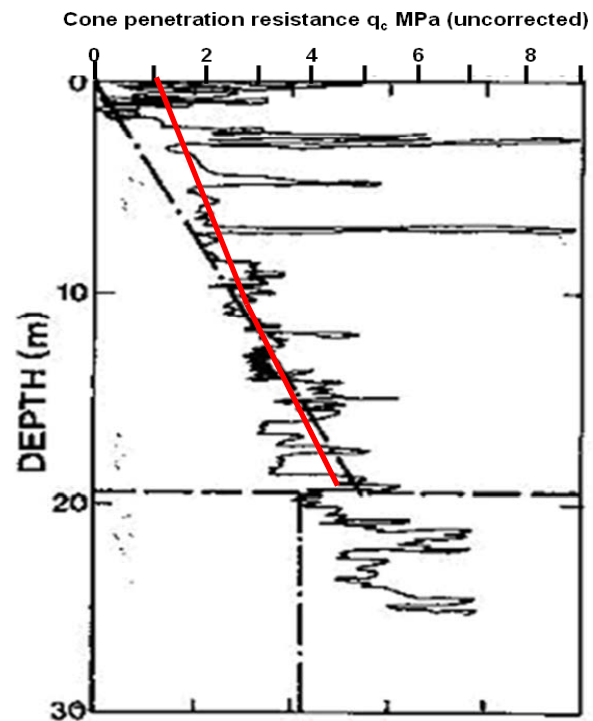
Man made ground, clayey sand, gravel

Below 3 to 4 m

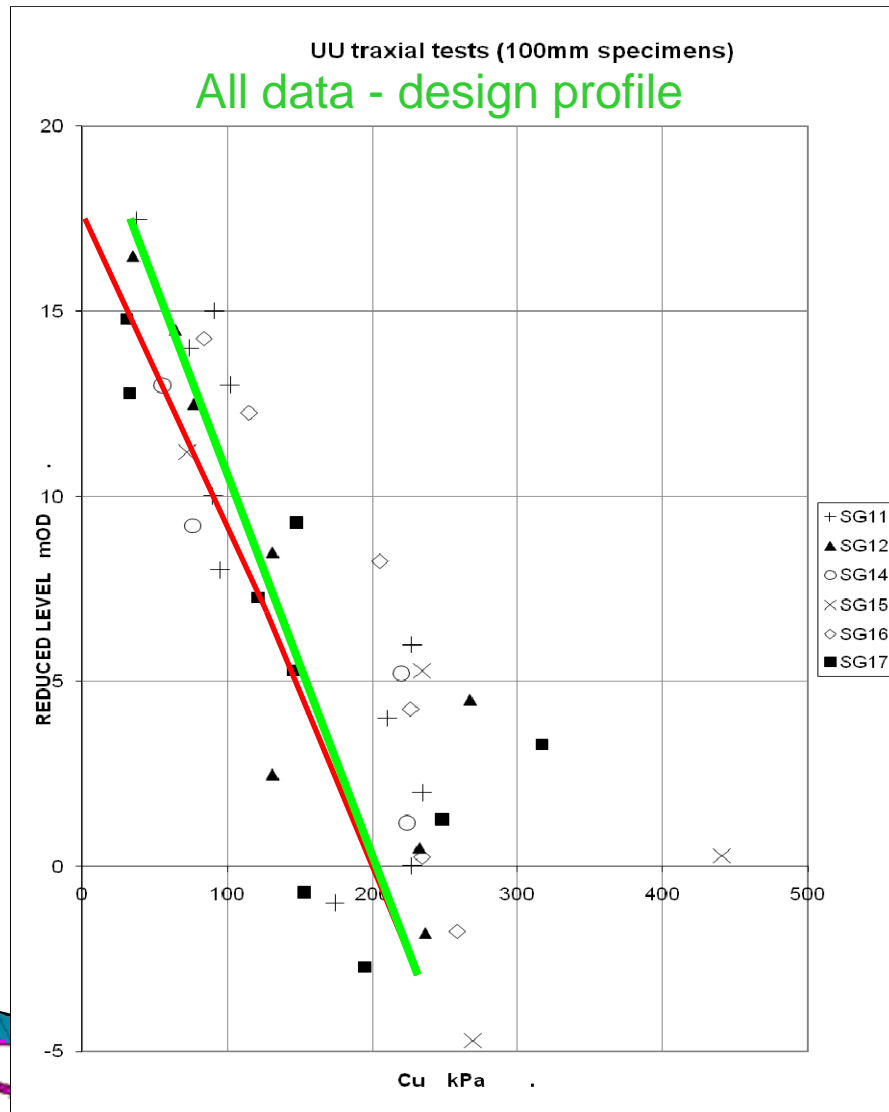
London CLAY – Cu: 30 – 230 kPa

Below 34 m

SAND



Undrained shear strength based on UU-tests



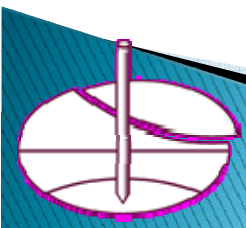
Questions asked

1st Question 17 Respondents from D, UK, PT, PL, IT:

- Permanent load 300 kN, variable load 150 kN downward
- SLS maximum settlement 20 mm
- SLS-State – required pile length?
- ULS-State – required pile length?

2nd Question – 7 Respondents:

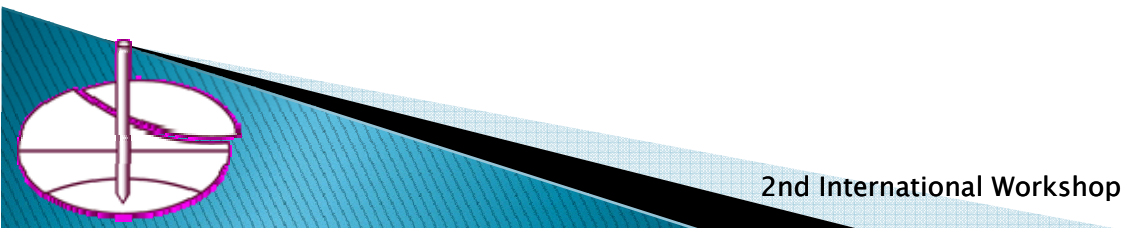
- Repeat the exercise using the given C_u design values (red lines)



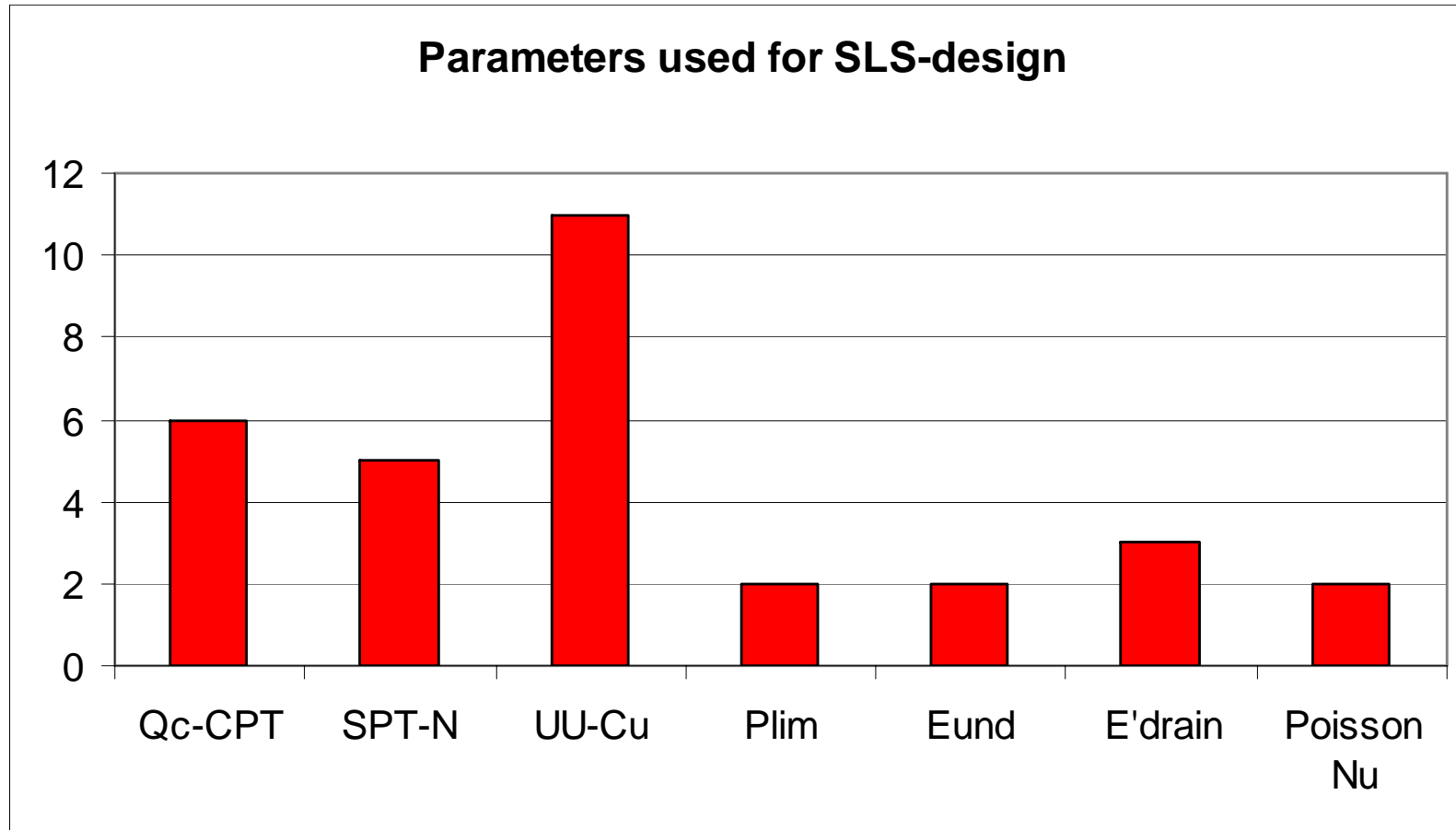
General Results

Observations:

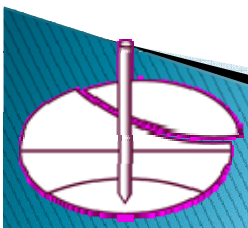
- 13 (of 17) have designed more than 3 piles in clay
- 15 (of 17) are confident in a sound EC7 design
- 9 used an average of all tests
- 8 used nearest test results, took location into account
- 13 (of 14) assumed a linear/bilinear/stepped variation of C_u or E with depth



Where were the Parameters for SLS-design based on?

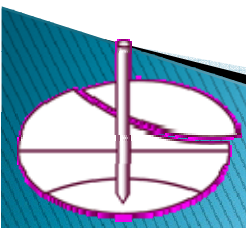


More than one answer was possible!



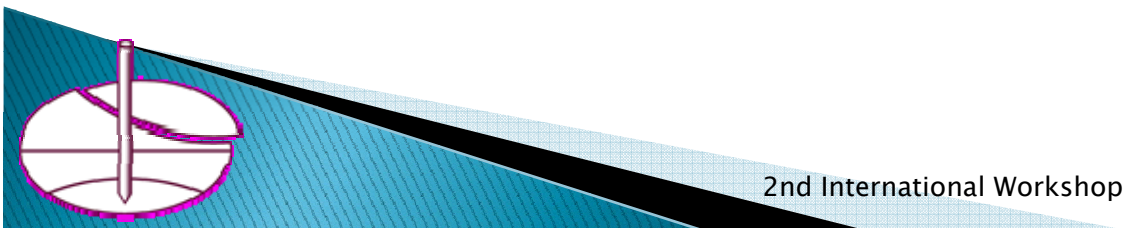
Correlations for parameter assessment

- Relation E_{und} and OCR, Duncan et al
- $C_u = 4.5 N - SPT$, Stroud
- Adhesion factors, Tomlinson
- DIN 1054
- Correlations UU and q_c , Kempfert
- Transform functions for bored piles, Gwizdala et al
- EA Pfahle
- Correlation C_u and Plasticity Index, Duncan et al.
- Relation $E' / N60$ (SPT), Stroud



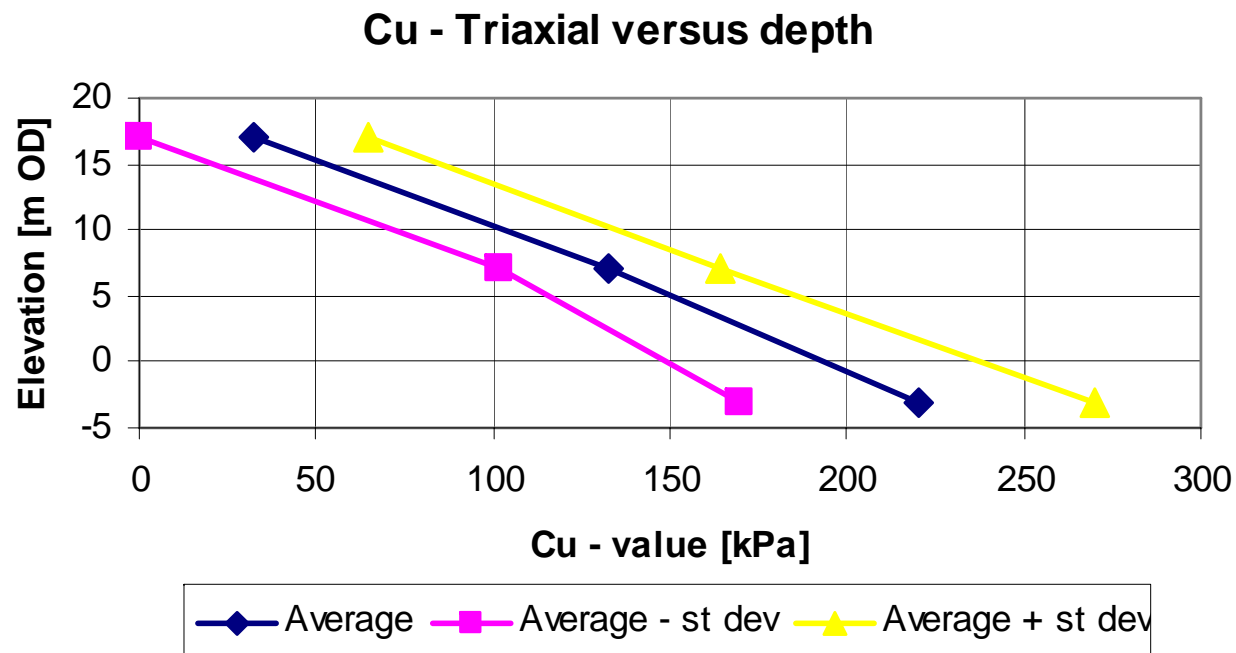
How did you derive at the characteristic values?

Answer	No	Comments
By eye	9	
Linear regression	3	
Existing standard	2	DIN 1054, EN1997-1
Published correlation	2	CIRIA, SPT-Stroud
Other	5	



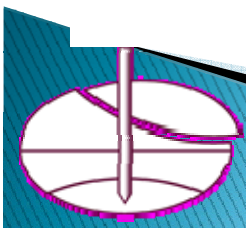
Characteristic values for SPT-N, CPT- q_c , Plim and Triaxial Cu

Questions 11 – 13 (q_c , Plim, SPT-N) not answered
→ Only characteristic values CU-value (Q14)



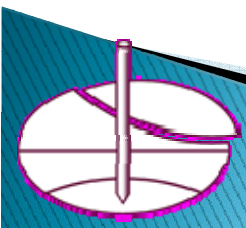
Each participant
converted test
result back to
Cu-value

Not many
differences
between countries
Variation σ/μ : 0,2



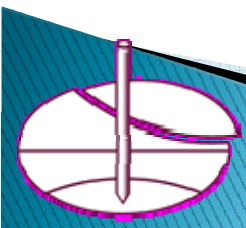
Method of calculation – Pile settlement

- No method from the national Annex (Annex F is N.A.)
- German standard DIN 1054, Annex B
- EA-Pfahle, German method
- Wide range of handbooks, references:
 - Linear elastic solution
 - T-z, q-z curves, Fellenius
 - Transform functions method
 - T-z curves Reese & Wang (1990)
 - Poulos and Davis (1980)
 - Randolph and Clancy (1993)
 - Piglet, Randolph
 - Tomlinson

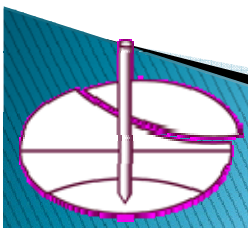
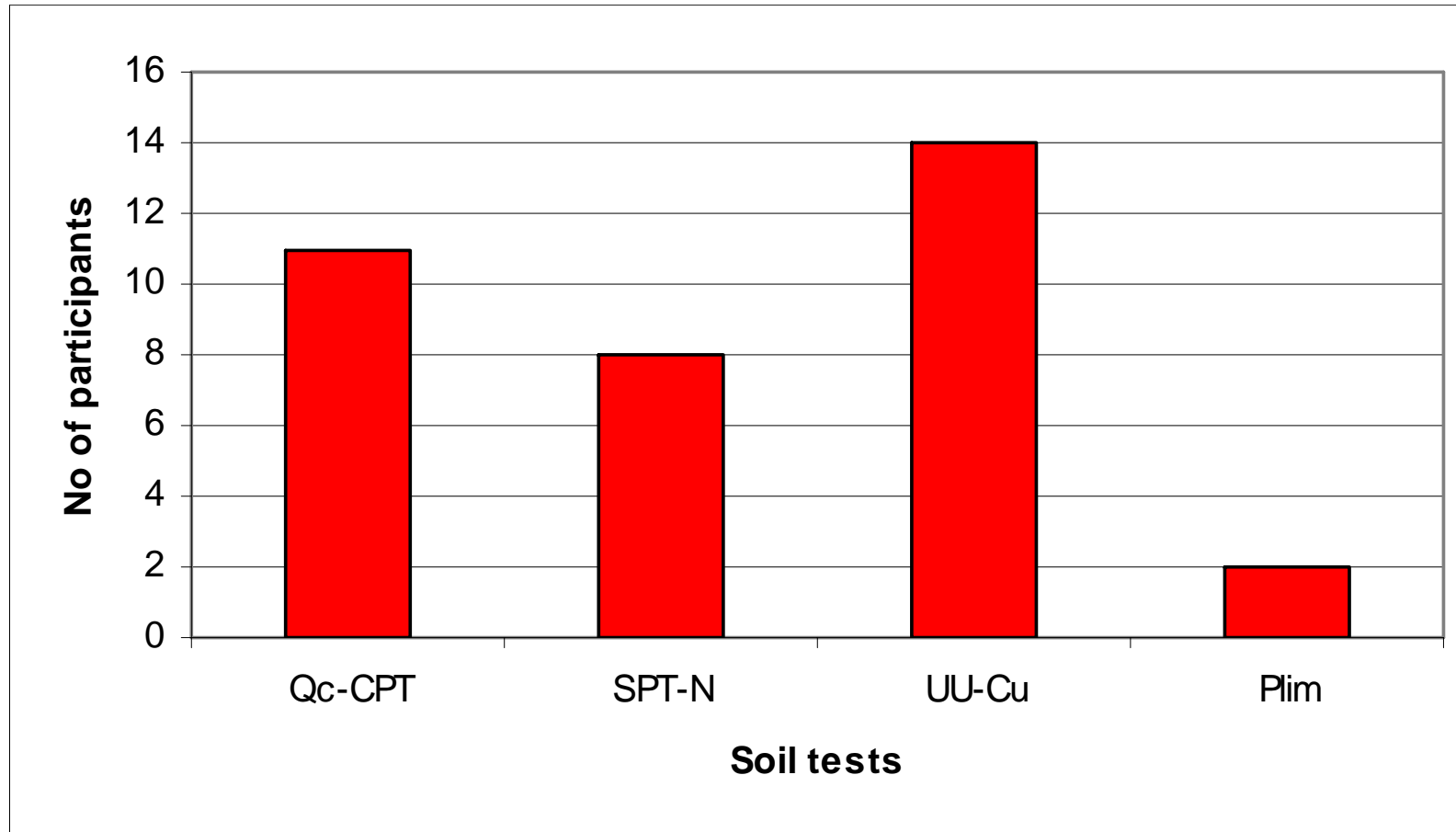


Q17 – Which length is needed in SLS – state?

- 12 Answers received
- Average pile length is 14 m
- Standard deviation of 2.8 m – variation 20 %
- All countries in the same range

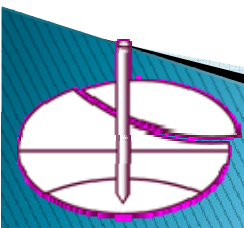


Tests used for ULS Pile design

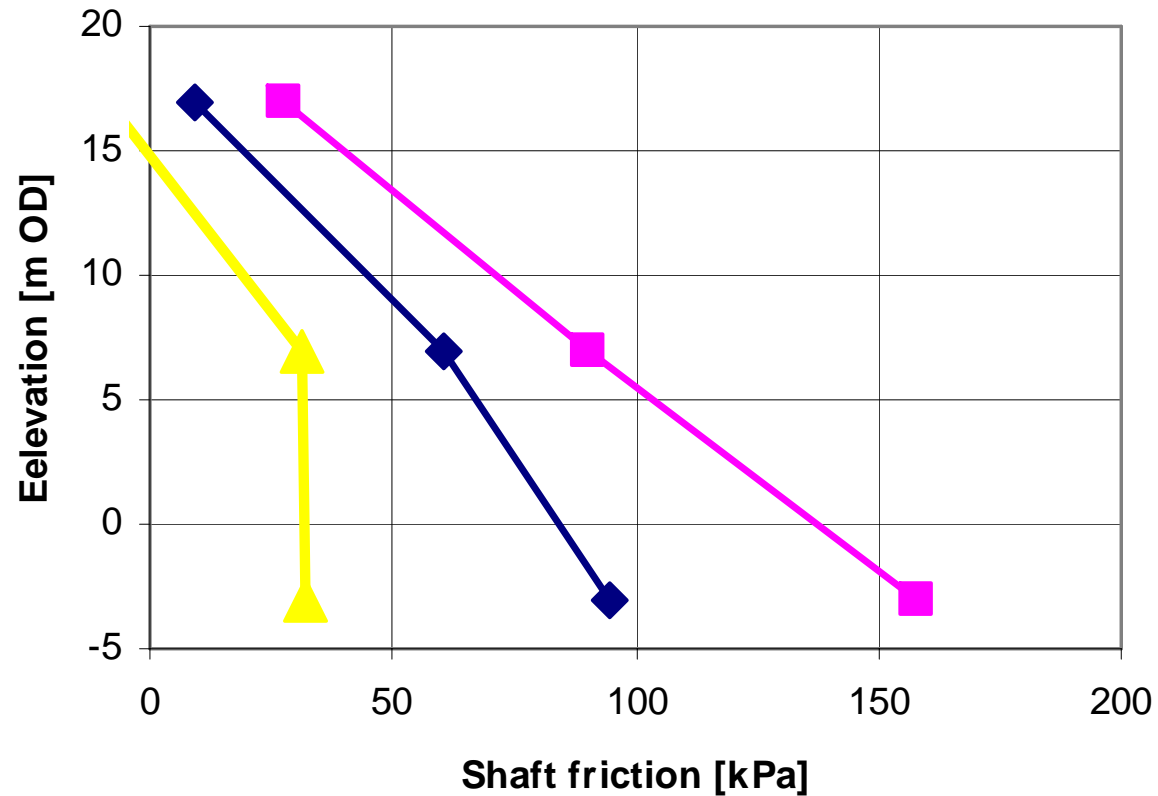


Correlations for ULS design

- Wide range of correlations:
 - DIN 1054
 - $C_u = 4.5 N$ (SPT) or $f_1 * N$ (SPT), Stroud
 - Tomlinson, adhesion factor a for piles
 - Kempfert et al, Correlation from UU-test to cone resistance
 - Polish piling code PN-B-02482
 - German code EA-Pfahle
 - Cone $q_c = C_u * N_c + \sigma_{v0}$
 - CPT - c_u correlation Meigh (1987, CIRIA)
 - DIN 4094-1: 2002-06 (CPT)
 - Baguelin et al, 1978 (pressuremeter)



Characteristic values of Unit Shaft Resistance



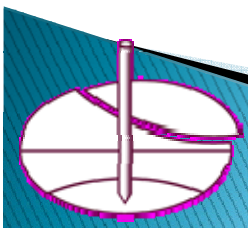
$Q_{shaft,k}$ at 7 m OD

Countries:

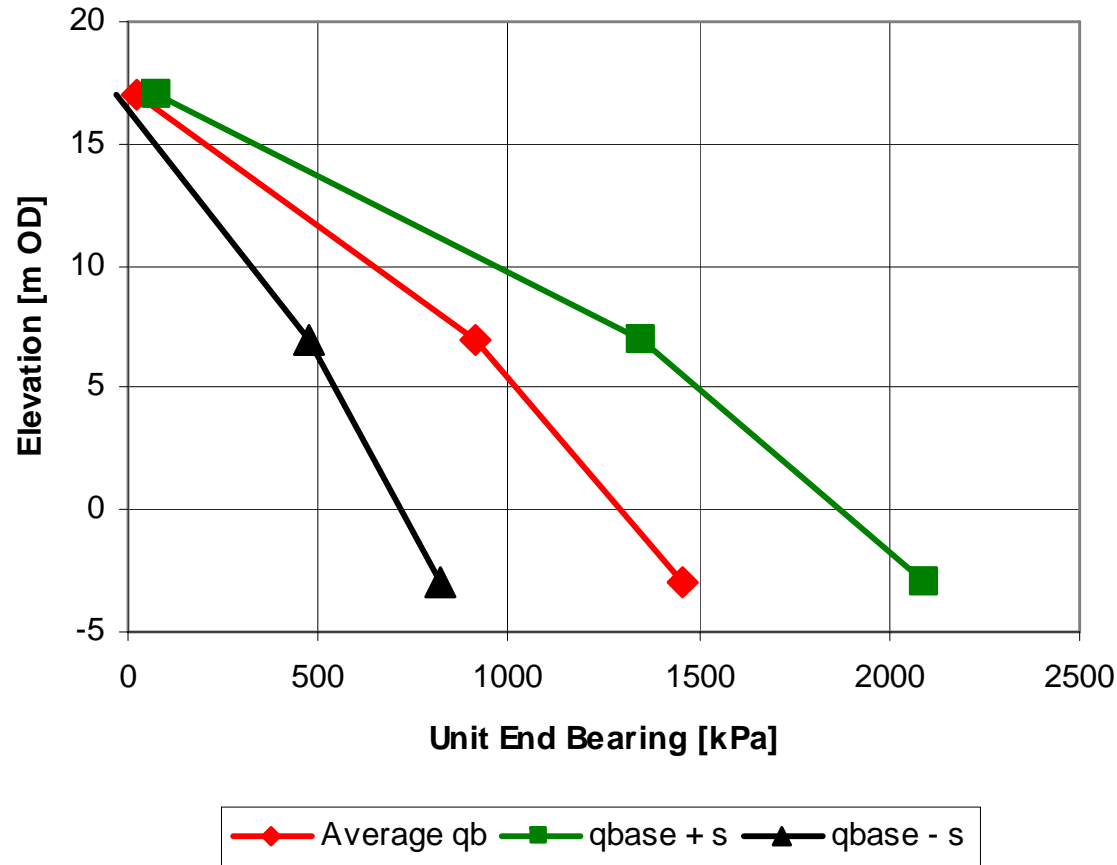
D, I, PL, PT → 55 kPa

UK → 80 kPa

◆ Average q_s ■ $q_{shaft} + s$ ▲ $q_{shaft} - s$



Characteristic values – Unit Base resistance



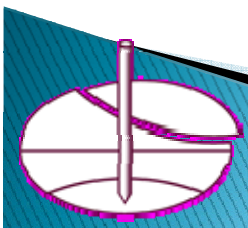
$Q_{base,k}$ at -3 m OD

Countries:

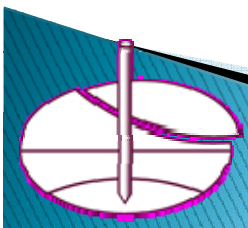
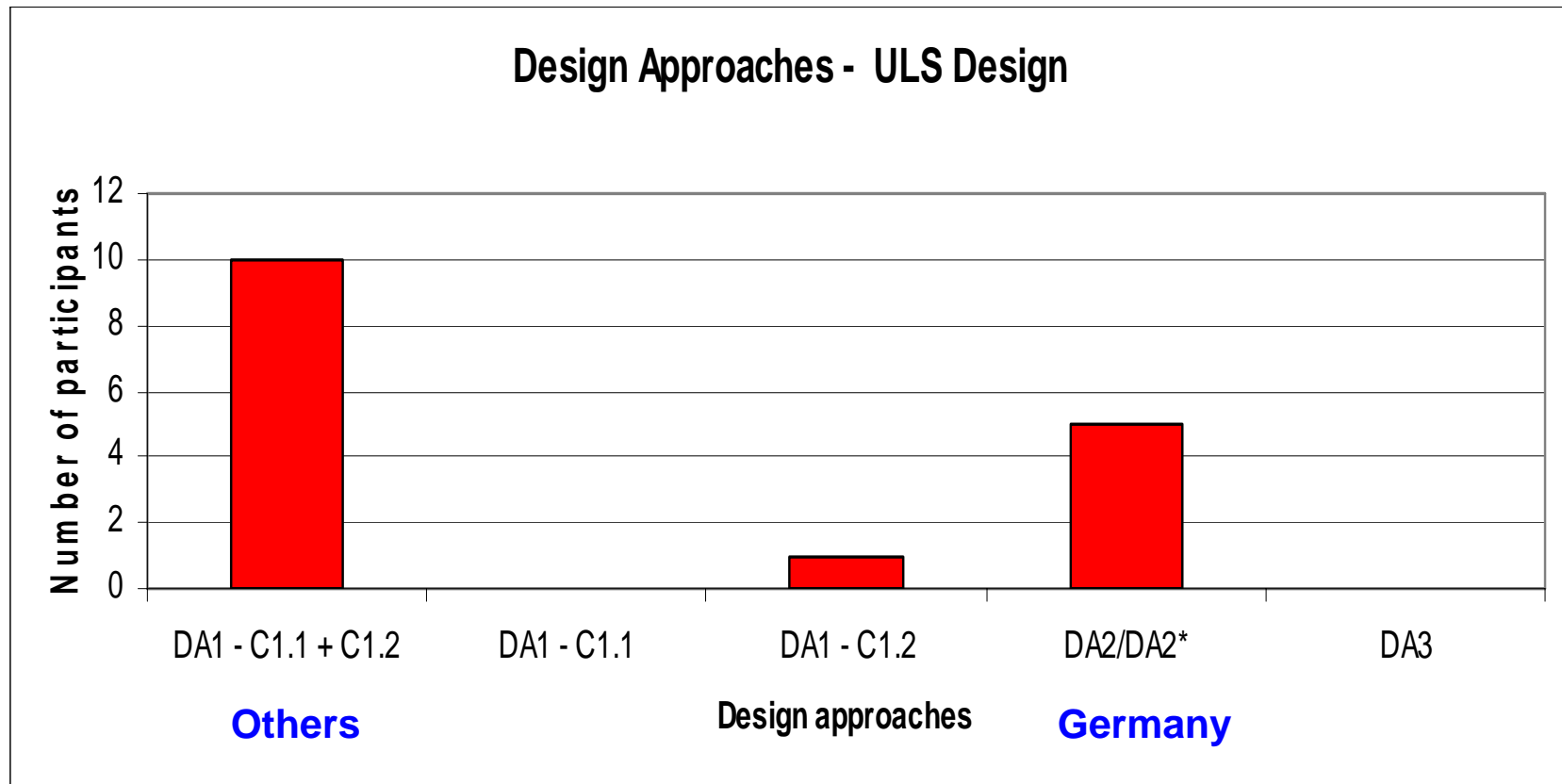
D, I, PL, PT → 1750 kPa

UK → 700 kPa

(UK applies a model factor of 1.4 in achieving at characteristic values)



Use of Design Approaches



Use of Partial Safety Factors in ULS-check

Load factors

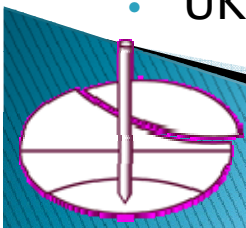
- All participants: DA1 – Comb. 1, DA2 $\rightarrow \gamma_G = 1.35 \gamma_Q = 1.5$
DA1 – Comb. 2 $\rightarrow \gamma_G = 1.0 \gamma_Q = 1.3$

Partial factors on strength

- Generally no partial factors on Cu (DA3) were applied
- Partial factors on shaft/base friction acc Nat Annexes:
 - DA1 – Comb. 1 $\rightarrow \gamma_{\text{shaft}} = 1.0 \gamma_{\text{base}} = 1.0$ (PL/PT: 1.25)
 - DA1 – Comb. 2 $\rightarrow \gamma_{\text{shaft}} = 1.3/1.45/1.6 \gamma_{\text{base}} = 1.6/1.7/2.0$
 - DA2 $\rightarrow \gamma_{\text{shaft}} = 1.1/1.4 \gamma_{\text{base}} = 1.1/1.4$
 - ξ -factors: ξ_4 (9x) $\rightarrow 1.135$ to 1.7 , ξ_3 (2x) $\rightarrow 1.45$

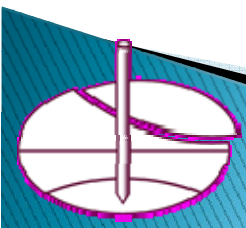
Partial model factor

- UK / PT \rightarrow partial model factor of $1.4 / 1.5$ on Cu



Results of the Analyses – ULS Pile length

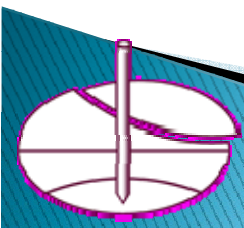
- 16 answers received
- Average pile length is 15.1 m (SLS 14.0 m)
- Standard deviation of 2.7 m (SLS 2.8 m)
- UK – pile length 12.5 m
- Italy – pile length 17.5 m
- Others – pile length ca. 15 m



Conclusions – Example bored pile in clay

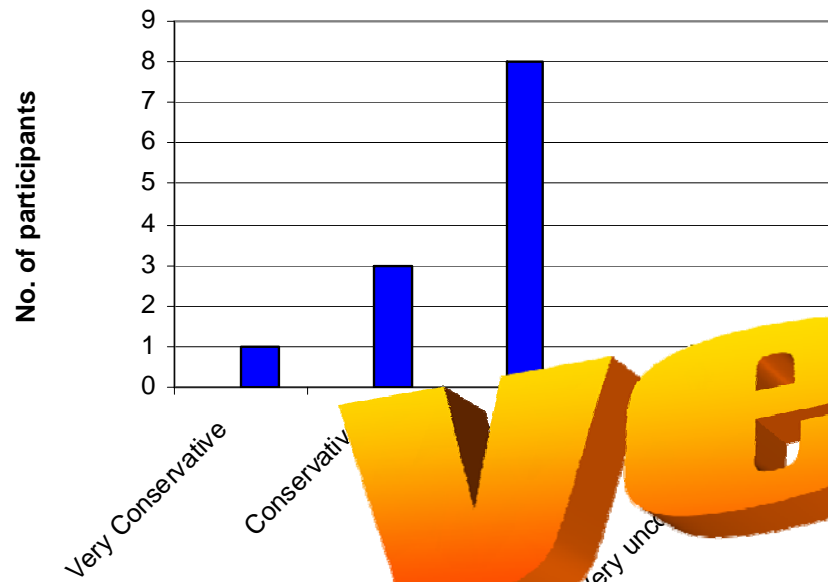
- 17 participants from 5 countries!
- All answers translated soil data to C_u -value using many correlations!
- Variation of Characteristic values of C_u (no anomalies, below level + 7 m) within 10 %.
- Many SLS-methods, less ULS-methods (all based on C_u)
- Good agreement load factors + Design load (630 kN)
- Spread in γ_{shaft} and γ_{base} in DA1 – Comb 2 (and DA2?)
- Use of partial model factor?
- Variation computed pile length (SLS and ULS) ca. 20 %

Thanks for all contributions!

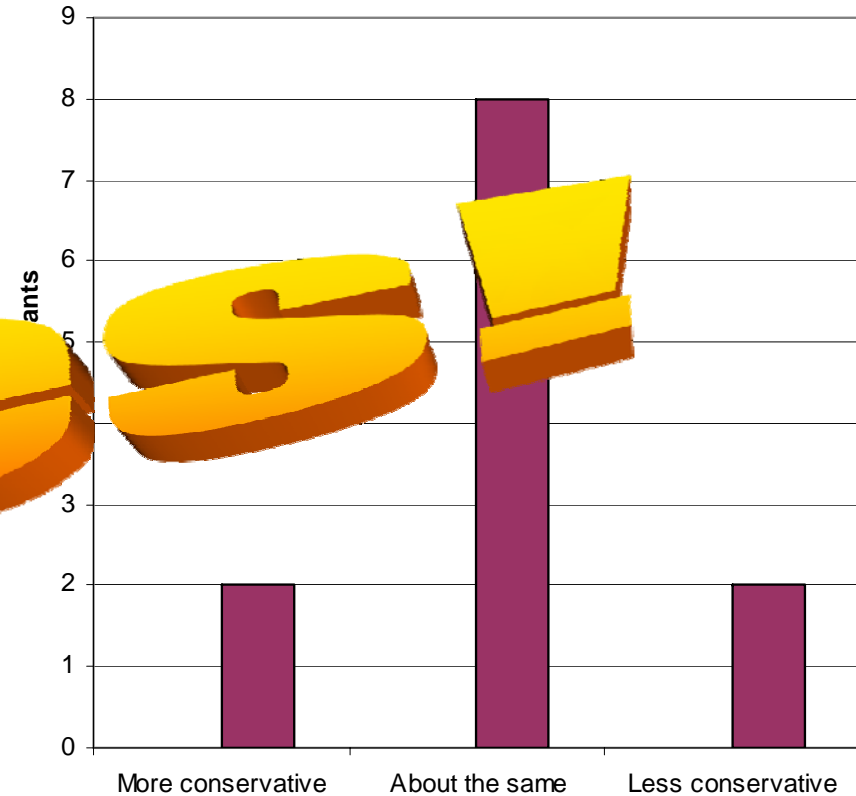


Are we confident in Eurocode Design??????

Is EC7 - Design Conservative?



Comparison EC7 with previous design



YES!

